Erosion of Materials by Fusion Plasma and Implications for U.S. and International Magnetic Fusion Energy Programs

by W. R. Wampler

Motivation—Erosion and redeposition of materials by fusion plasmas impacts lifetime of plasma-facing components and tritium inventory that are critical issues for next-step magnetic fusion energy devices such as the International Thermonuclear Experimental Reactor (ITER). Erosion and deposition of materials by fusion plasmas are complex processes, and experiments are necessary to determine rates of erosion and deposition in tokamaks. Ion beam analysis (IBA) is one of the principal experimental methods to examine erosion and redeposition and has been used at most tokamaks throughout the world. The Ion Beam Materials Research Laboratory (IBMRL) at Sandia, in collaboration with US Plasma Physics Laboratories, has been conducting experiments to measure rates of erosion and deposition in US tokamaks.

Accomplishment—Early studies in the TFTR tokamak at the Princeton Plasma Physics Laboratory (PPPL) showed that a large fraction (40%) of deuterium used to fuel plasmas remained inside the vessel due to codeposition with carbon eroded from plasma-facing components. These IBA measurements of fuel retention provided key information needed to plan subsequent tritium plasma operation and machine conditioning procedures in TFTR that led to the achievement of 11 MW fusion power with the constraint of keeping the on-site tritium inventory below 5 grams.

Erosion and redeposition of materials by divertor plasmas have been extensively studied using the Divertor Materials Evaluation System (DiMES) in the DIIID tokamak, which enables controlled exposure of probes to well characterized plasmas. The rate of erosion at the outer strike-point (OSP) was measured for various materials and plasma conditions. Erosion rates decreased with increasing atomic mass (see Fig. 1) consistent with erosion by physical sputtering by light ions. Erosion of carbon is also enhanced by hydrocarbon formation. Detaching the edge plasma through cooling by injecting deuterium gas greatly reduced erosion, but cooling by injection of neon caused very high carbon erosion.

Erosion, deposition and deuterium retention were also studied in Alcator C-Mod at MIT, which has molybdenum instead of carbon plasma-facing components. The erosion rate of molybdenum was low and similar to values measured in DIIID (see Fig. 1). Deuterium retention was also low. These results show that codeposition with redeposited material, the principal mechanism of long-term deuterium retention in tokamaks with carbon plasma facing components, is greatly reduced in C-Mod. Sandia and PPPL are also conducting studies of erosion, deposition and wall conditioning in the National Spherical Torus Experiment (NSTX).

Significance—The design and choice of plasma-facing materials for next-step magnetic fusion experiments are based on knowledge obtained from studies of erosion and deposition in present machines. Carbon components are widely used in present tokamaks because of their resistance to thermal damage, but have erosion and tritium retention rates that are unacceptably high for next-step machines. Proposed burning plasma experiments, ITER and FIRE, thus avoid carbon where possible and use beryllium in the main plasma chamber and tungsten in the divertor (see Fig. 2). Divertor plasmas will be detached to reduce heat flux and erosion in the divertor. These next step machines will explore burning plasma conditions required for a fusion reactor and are planned to be built and tested in the next decade.

Sponsors for various phases of this work include: DOE Office of Fusion Energy Sciences
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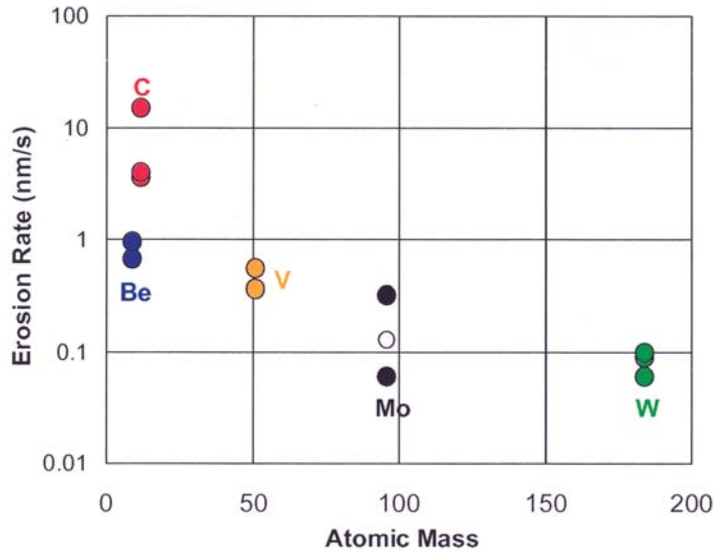

Figure 1. Erosion rates of various materials measured by IBA at the divertor strike point in DIIID (solid symbols) and C-Mod (open symbol) tokamaks.

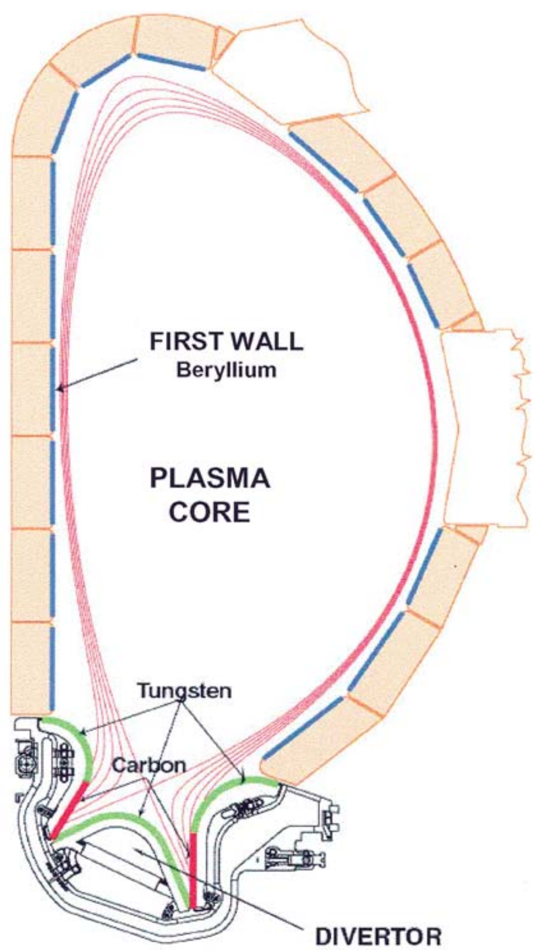

Figure 2. The ITER design uses a beryllium wall in the main plasma chamber, and a lower divertor with carbon and tungsten. The nested red lines show magnetic field contours in the plasma boundary.